STRUCTURE OF SIERRA PILARES, MUNICIPIO DE OJINAGA,

CHIHUAHUA, MEXICO

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by

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas in Partial Fulfillment

of the Requirements

For the Degree of

MASTER OF ARTS

THE UNIVERSITY OF TEXAS

June 1959

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Franklin W. Daugherty

A B S T R A C T

The map of the Sierra Pilares of the Chihuahua tectonic belt shows an asymmetric north-trending anticlinal fold of Laramide origin that owes most of its relief to Tertiary basin and range block faulting. This has been named the Borrachera anticline. A large thrust sheet is exposed along the southern boundary of the map area; overthrusting from west to east towards the Diablo Platform fits the regional pattern of thrusting. Tertiary block faulting produced numerous normal faults trending subparallel to the fold axis.

A study of 49 joint trends in the Hawkeye limestone in the Borrachera anticline indicates that the maximum compressive stress orientation was east-west. Some joints were formed before the folding, others during the early stages of the folding episode.

Petroleum production is possible from the Borrachera anticline; large supplies of underground water are available from bolson fill; metal production is unlikely.

C O N T E N T S

TEXT

ILLUSTRATIONS

Maps

Columnar Sections

Diagram

Photographs

INTRODUCTION

PURPOSE

The Sierra Pilares is a small part of the extensively folded and thrust-faulted mountains of northern Chihuahua that comprise the Chihuahua tectonic belt. The mountains are composed chiefly of Lower Cretaceous geosynclinal sedimentary rock that has been deformed by Laramide folding, cut by Tertiary block-faulting, and subsequently dissected by erosion.

The purpose of this investigation under the supervision of Professor R. K. DeFord, Department of Geology, The University of Texas, is to describe the structural geology of the Sierra Pilares. A similar report is being prepared by Vest (1959) on the structural geology of the northerly adjacent Sierra Porvenir.

LOCATION

The map area of approximately 75 square miles is geographically a part of the basin and range country in extreme northeast Chihuahua, Mexico, adjacent to the international boundary. The eastern boundary of the map area is the Rio Bravo or Rio Grande. The mapping extended to the northern edge of an extensive thrust sheet about Latitude 30°22' N., west approximately to Longitude 105°05' W., and north to Latitude 30°28' N.

Explanation of Figure 1

Area		Mapped during
1.	Candelaria Mapped by Buongiorno, Carlisle, Duchin, Mankin, McGrew, Peterson, Sewell, and J. T. Smith.	1954
2.	Pinto Canyon Mapped by Amsbury.	1953-55
3.	Porvenir Mapped by Bilbrey, C. R. Colton, J. D. Ferguson, McKinney, W. D. Miller, and Schulenberg.	1956
4.	Van Horn Mountains Mapped by Twiss.	1956-57
5.	Sierra de los Fresnos Mapped by R. Allen and J. C. Nichols.	1956
6.	Indio and Eagle Mountains Mapped by Underwood.	1956-59
7.	Northern Rim Rock Mapped by Braithwaite, Bridges, Dasch, and Frantzen.	1957
8.	Northern Sierra Pilares Mapped by Clutterbuck and Ferrell.	1957
9.	Sierra del Porvenir Mapped by Harwell and Vest.	1958
10.	Sierra Pilares Mapped by Campbell and Daugherty.	1958

Erratum: From Valentine the railroad follows the highway to Marfa. It does not run eastward.

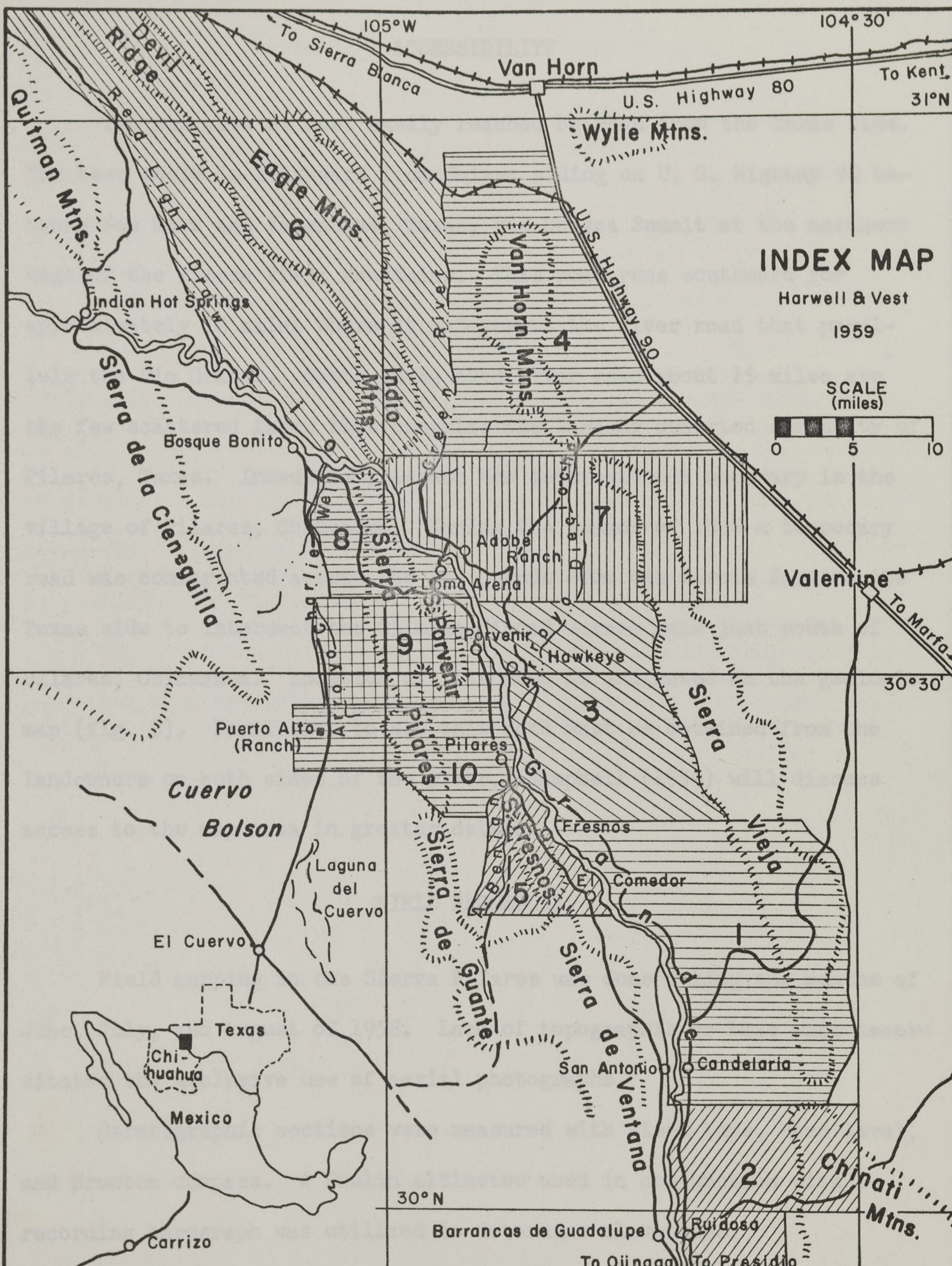

INDEX MAP
Harwell & Vest
1959
SCALE
(miles)
0
5
10
105°W
104° 30'
31°N
30°30'
30°N
To Sierra Blanca
Van Horn
U.S. Highway 80
To Kent
Wylie Mtns.
Devil Ridge
Red Light Draw
Quitman Mtns.
Eagle Mtns.
6
Indian Hot Springs
Sierra de la Cieneguilla
Rio Grande
Bosque Bonito
Indio Mtns.
Green River
Van Horn Mtns.
4
U.S. Highway 90
7
Adobe Ranch
Loma Arena
Valentine
To Marfa
8
Sierra Parvenir
Charlie Well
9
Porvenir
Hawkeye
3
Sierra Vieja
Puerto Alto (Ranch)
Arroyo
Pilares
Sierra Pilares
10
Cuervo Bolson
Fresnos
S. Fresnos
5
El Comedor
Laguna del Cuervo
Sierra de Guante
Sierra de Ventana
1
El Cuervo
Texas
Chihuahua
Mexico
San Antonio
Candelaria
2
Chinati Mtns.
Barrancas de Guadalupe
Ruidosa
Carrizo
To Ojinaga
To Presidio

Figure 1

ACCESSIBILITY

The map area is most easily reached by road from the Texas side. The best route is southward from Chispa siding on U. S. Highway 90 between Van Horn and Valentine, Texas, via Chispa Summit at the northern edge of the Tierra Vieja Mountains. This road runs southward for approximately 18 miles where it intersects the river road that parallels the Rio Grande. South along this river road about 15 miles are the few scattered farms that comprise the largely deserted community of Pilares, Texas. Immediately across the international boundary is the village of Pilares, Chihuahua. During the summer of 1958 a temporary road was constructed across the Rio Grande from the Garcia farm on the Texas side to intersect the Ojinaga-Ciudad Juarez road just south of Pilares, Chihuahua. Location of this road is indicated on the geologic map (fig. 3). Permission to use this road must be obtained from the landowners on both sides of the river. Campbell (1959) will discuss access to the map area in greater detail.

FIELD PROCEDURE

Field mapping in the Sierra Pilares was done during the months of June, July, and August of 1958. Lack of topographic or base maps necessitated the exclusive use of aerial photographs.

Stratigraphic sections were measured with steel tape, hand level, and Brunton compass. A Paulin altimeter used in conjunction with a recording barograph was utilized to determine elevations.

Field transportation was by four-wheel-drive jeep, a necessity for travel along the arroyos and terraces to the inner parts of the area as well as along the more primitive Mexican roads.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to the many people who rendered assistance during the preparation of this report. He is especially indebted to Professor Ronald K. DeFord for his guidance and helpful suggestions both in the field and during the preparation of this report. Thanks are due Dr. Stephen E. Clabaugh and Dr. John L. Snyder for serving on the thesis committee. The cooperation of Richard A. Campbell, his field partner, is gratefully acknowledged.

Special thanks are due Ing. Raul Perez and Ing. Teodoro Diaz of Petroleos Mexicanos for supplying aerial photographs of the map area.

G E O G R A P H I C   N A M E S

The geologist who visits this region faces a multiple problem. There is no comprehensive map; and many of the maps available contain inaccuracies, especially with respect to geographic names and roads, that make orientation difficult.

One of the misconceptions that has been perpetuated in print is the location of the Sierra Pilares. A chain of mountains extends from the vicinity of Sierra Blanca, Texas, to La Mula, Chihuahua, beyond Ojinaga (DeFord, 1958a, p. 12, and fig. 1). The writer does not agree that the name "Sierra Pilares" properly includes all that part of the range that extends southward from the Rio Bravo to the Sierra Ventana. For example, Clutterbuck (1958) and Ferrell (1958) wrote, respectively, on the structure and stratigraphy of the "northern Sierra Pilares." As a matter of usage, the feature that they mapped is Sierra Bosque Bonito.

Accepted local usage defines the northernmost portion of this mountain range as Sierra Bosque Bonito. Adjoining it to the south is Sierra Porvenir mapped by Harwell (1959) and Vest (1959). Sierra Porvenir is joined to the south by Sierra Pilares, which is joined southward in turn by Sierra Guante. There seems to be no local name in use for the range as a whole, because it is topographically four fairly distinct divisions.

The problem of nomenclature arises because "sierra" in Spanish may mean either a mountain or a mountain range. It has been argued that the village of Pilares derived its name from the Sierra Pilares, and that, therefore, Sierra Pilares might well be the name for the entire range rather than a portion of it. On the other hand, if it could be established that the name for the village antedated the name of the mountain, this would further strengthen the writer's belief that Sierra Pilares is a local rather than a regional name.

Madison and Stillwell (1958, p. 102) err in reporting that the village of Pilares gets its name from the Spanish word meaning "waterhole." The responsibility for naming Pilares can be firmly placed on the shoulders of El Capitan Commandante y Commissario Don Joseph de Ydoiaga (or Ydoyaga), who made a reconnaissance and census-taking expedition to the junction of the Rio Conchos and Rio Bravo and environs in 1747. Capitan de Ydoiaga named the site occupied by an old Deer Indian village on the north bank of the Rio Bravo "Las Pilares," because it was near two clay pillars, developed on a miniature badlands topography (de Ydoiaga, 1751, p. 77). His own words follow:

> el dia veinte cruce el rio, a la banda del Norte, por lo que sierra, las del sur y continue mi marcha, apartado del, segun daban lugar, las obras de las serros, y hauiendo caminado como seis leguas, pare en la rancheria bieja, que llaman de los Benados, ymmediato al rio, frontero, de dos pilares, que estan en una loma pequena, y a los alrredores manadas de barro, de barios colores, y le puse por nombre, las pilares.

Where a local name in Mexico is unknown or is in doubt, a perusal of the records of Spanish explorations will probably furnish a name.

Many of the place names in Mexico today are of long standing and usually differ only in spelling from their original names. For the reader who wishes more information on Mexican place names, the Archives Collection of The University of Texas has a number of transcripts of documents pertaining to the early exploration and settlement of the Spanish colonies. Transcripts relating especially to Chihuahua up to 1802 are catalogued under "Audiencia de Guadalajara, Archivo General de Indias."

Perhaps later investigators can resolve the Sierra Pilares controversy by finding a name in use for the entire range. Until such time "Pilares Range" should be used.

Figure 2 shows the generalized relationship of the four distinct divisions of the Pilares Range. Four bolsons are shown, two on each side of the range. Three have been breached by the Rio Bravo; one is still intact. Benigno bolson is named from Arroyo Benigno which drains northward to the Rio Bravo. The Green River bolson, which is north of the Benigno bolson and is separated from it by a threshold just east of Porvenir Mountain, continues northward into Texas, where it lies between the Indio Mountains on the west and the southern end of the Van Horn Mountains on the east. To the south on the western side of the range is Cuervo bolson. Adjoining it on the north is Charlie Well bolson, which derives its name from the northward draining Arroyo Charlie Well.

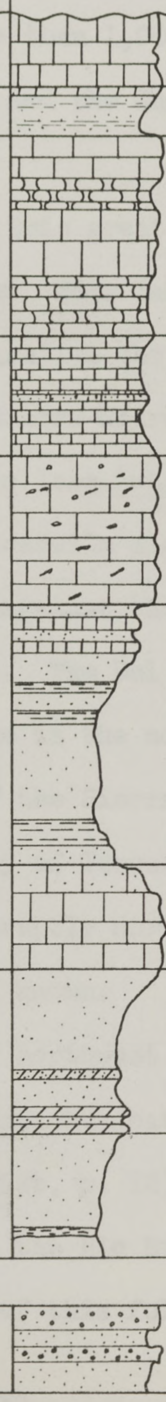
Local residents recognize only the Cuervo bolson as a topographic feature, since it is the only one of the four that remains undissected. The local name is Bolson de Cuervo, which has no geological connotation. The American geologist will prefer to use the name Cuervo bolson in order to accord with geological terminology.

The river that Anglo-Americans call the Rio Grande was known by the Spanish as the Rio Bravo del Norte or Rio Grande del Norte. During the last century the Mexicans generally discarded Rio Grande del Norte and shortened Rio Bravo del Norte to Rio Bravo. In this thesis, Rio Bravo is used when reference to the river is made from the Mexican side. In all other cases Rio Grande is used.

S T R A T I G R A P H Y

The accompanying columnar section (sec. 1) briefly describes the rocks that crop out in the Sierra Pilares. For a more detailed description of the stratigraphy of the map area, the reader is referred to Campbell (1959).

DIAGRAMATIC STRATIGRAPHIC SECTION OF CRETACEOUS ROCK IN SIERRA PILARES



SYSTEM	SERIES	EUROPEAN STAGES		PROVINCIAL SERIES	CENTRAL TEXAS GROUPS	FORMATIONS OF SIERRA PILARES	DESCRIPTION	THICKNESS IN FEET
CRETACEOUS	UPPER	CENO-MANIAN		COMANCHE	WASHITA	BUDA Ls.	MEDIUM GRAY, UNFOSSILIFEROUS, APHANITIC LIMESTONE	95
						DEL RIO Fm.	YELLOWISH BROWN, SHALY SANDSTONE WITH LIMESTONE CONTAINING EXOGYRA CARTLEDGEI	17
	LOWER CRETACEOUS	ALBIAN	UPPER			* BOSQUE BONITO ls.	NEARLY WHITE TO BROWN, MASSIVE SILICA CEMENTED SANDSTONE WITH BEDS OF LIMESTONE NEAR TOP AND BASE, AND INTERBEDS OF RED AND GREEN SHALE: PERCENTAGE OF SHALE INCREASES TOWARD BASE: UPPER THIN LIMESTONE BEDS CONTAIN EXOGYRA, TOUCASIA, ACTAEONELLA, LUCINA.	1,004
						* LUJAN ls.	MEDIUM BROWN, ARENACEOUS, NODULAR LIMESTONE WITH INTERBEDS OF DARK GRAY, CALCAREOUS SHALE: MIDDLE PART CONTAINS OXYTROPIDOCERAS, TRIGONIA, GRYPHAEA, EXOGYRA, PINNA; LOWER PART CONTAINS DIPOLOCERAS, OXYTROPIDOCERAS, PROTOCARDIA.	311
			MIDDLE		FREDERICKSBURG	* GUANTE ls.	LIGHT YELLOWISH BROWN, MASSIVE BLUFF-FORMING LIMESTONE WITH ABUNDANT CHERT NODULES, CONTAINS SILICIFIED PECTEN, OSTREA, TOUCASIA, NEITHEA.	770
			?		?–?	COX Ss.	NEARLY WHITE TO BROWN, MASSIVE, ORTHOQUARTZITE SANDSTONE WITH BEDS OF LIMESTONE NEAR TOP AND BASE, AND INTERBEDS OF RED AND GREEN SHALE; THE PERCENT OF SHALE INCREASING TOWARD BASE; UPPER THIN LIMESTONE BEDS CONTAIN EXOGYRA, TOUCASIA, ACTAEONELLA, LUCINA.	1,414
			LOWER		TRINITY	* HAWKEYE ls.	LIGHT GRAY, MASSIVE, PAUROGRAINED TO MICROGRAINED LIMESTONE CONTAINING ORBITOLINA TEXANA	242
						* PORVENIR ss.	LIGHT YELLOWISH GRAY TO DARK BROWN, CALCAREOUS SANDSTONE, NONRESISTANT, OOLITIC WITH INTERBEDS OF SILTSTONE; BEDS OF DARK GRAY, APHANITIC LIMESTONE TOWARD BASE CONTAINS TRIGONIA, OSTREA, DUFRENOYA, EXOGYRA, CTENOSTREON.	748
		APTIAN				* PILARES ss.	LIGHT BROWNISH GRAY, WELL ROUNDED SANDSTONE WITH A FEW PEBBLY STRINGERS TOWARD BASE	426
						NOT EXPOSED		NOT EXPOSED
						PUDDINGSTONE	REDDISH GRAY, SILICIOUS CONGLOMERATE, CONTAINING CHERT, LIMESTONE, AND QUARTZ FRAGMENTS FROM PEBBLE TO SAND SIZE.	169

* *FIELD NAME NOT FORMALLY PROPOSED*

Section 1

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THE UNIVERSITY OF TEXAS
MAY 1959

R E G I O N A L   S T R U C T U R E

The Sierra Madre Oriental of Mexico is a great cordillera of folded Mesozoic sedimentary rocks that extends from the Isthmus of Tehuantepec northwestward for more than 1,000 miles. It is bounded by the Meseta Central on the west and the Gulf Coastal Plain to the east.

In south and central Mexico this great fold belt consists of a system of northwest-trending folds. Near Saltillo, Coahuila the fold belt turns abruptly westward to parallel the southern edge of the Coahuila Platform. Although the Sierra Madre turns west, its north-northwestward trend is continued in less intensely folded mountains that extend through the state of Coahuila along the eastern flank of the Coahuila Platform, to die out against the southern side of the Marathon Dome of Trans-Pecos Texas. The Del Norte Mountains along the western margin of the Marathon Dome is the northernmost element of this trend. From Saltillo the folds of the Sierra Madre continue their general westward trend to the vicinity of Torreon in extreme southwest Coahuila, where they turn again abruptly northwestward. Their extent beyond this second turn is not yet known.

The northwest-trending folds northwest of the railroad that extends from Ojinaga toward Ciudad Chihuahua have been termed the Chihuahua tectonic belt by DeFord (1958b, p. 72). This belt in northeastern Chihuahua mostly parallels the Rio Bravo, but two ranges cross the river. The easternmost range of this fold belt is formed by the southeast-to-northwest conjunction of the Sierras Grande, Ventana, Fresnos, Guante, Pilares, Porvenir, and Bosque Bonito in Chihuahua and the Indio and Eagle Mountains and Devil Ridge in Texas. The other range that crosses the Rio Bravo is called the Quitman Mountains in Texas (fig. 1).

The tectonism that produced the Sierra Madre Oriental produced the Chihuahua tectonic belt west of the Diablo Platform in Trans-Pecos Texas. The overthrusting was dominantly eastward toward the platform. The mountains and basins on the platform are composed of igneous intrusions and flat-lying, block-faulted Cretaceous sedimentary rock and Tertiary volcanic rock.

The Diablo Platform is a late Paleozoic feature from which the earlier Paleozoic rock has been largely eroded. It is capped by Permian limestone. The Triassic redbeds of West Texas wedge out against the eastern side of the platform. The Jurassic, Neocomian, and Aptian formations of the Chihuahua tectonic belt wedge out against the western side of the platform. The Albian limestones and sandstone are much thinner over the platform than west of it.

Tertiary block-faulting produced isolated intermontane basins between folds of the Chihuahua tectonic belt, and these basins have been largely filled with bolson deposits. The late integration of the Rio Grande and its tributaries drained many of these basins, removing part of the fill and leaving behind extensive but relatively thin Quaternary terrace gravels.

M E S O Z O I C   A N D   C E N O Z O I C   T E C T O N I C S

In Jurassic time, the southern part of the North American continent extended over much of the state of Coahuila and the eastern part of the state of Chihuahua (Kellum, et al., 1936, p. 1001). The stable Diablo Platform was bordered by the Chihuahua trough to the southwest.

A transgressing Jurassic sea in Mexico reached the site of the Malone Mountains in late Jurassic time according to Albritton (1938, p. 1803). It probably occupied the site of the Sierra Pilares in late Jurassic time also. This sea continued its northward transgression during early Cretaceous time and deposition continued until the end of the Comanchean Epoch. An epeirogenic uplift is indicated by the regional unconformity between the Comanchean and Gulfian series.

No strata of Gulfian age have been found in the Sierra Pilares but Ferrell (1958, p. 42) reported an outcrop of 115 feet of Chispa Summit Formation in Sierra Bosque Bonito. Miller (1957, p. 32) described the San Carlos Formation in the Porvenir area to the southeast as representing the final regression of the Gulfian sea.

In the Sierra Pilares the latter part of the late Cretaceous Epoch was marked by the beginning of the Laramide orogeny. During this orogeny the Chihuahua tectonic belt was subjected to east-west compression that resulted in the fold trends seen today. This deformation culminated in the Eocene.

The only outcrops of volcanic rock in the map area are along the banks of the Rio Bravo near its junction with Arroyo Benigno. To the east in the Rim Rock country a thick sequence of flowrock and tuff is present. Bridges (1958, p. 2) believed that this volcanic activity began in the Oligocene Epoch.

Following the vulcanism the block-faulting episode began producing the basin and range structural features. This great faulting was responsible for the thick accumulations of bolson fill in the intermontane basins thus created.

L O C A L   S T R U C T U R E

FOLDS AND THRUST FAULTS

The Sierra Pilares is a feature of Laramide folding of the Chihuahua tectonic belt. This part of the Pilares Range is a large asymmetric anticline that plunges gently southward. Vest (1959) named it the Borrachera anticline in his description of the Porvenir area. The plunge of the fold to the south averages about 14° with considerable local variation. The eastern flank dips at an average of 45° with maximum dips of 60°. The western flank has a more variable dip averaging 15°.

In the extreme northern part of the map area on the eastern flank of the fold, the Hawkeye limestone is thrust from west to east over the Cox Sandstone. The vertical and horizontal displacement of this fault is small. At this same locality there are four small north-trending anticlinal folds in the Cox Sandstone. They are interpreted as drag folds developed along the eastern limb of the Borrachera anticline, while that part of it in the Porvenir area to the north was overturned and then overthrust eastward.

On the western flank of the Borrachera anticline there are several small asymmetrical and overturned folds in the more argillaceous part of the Lujan limestone. These folds follow the regional pattern of overturning eastward.

In the northwestern edge of the map area several elongate northwest-trending ridges of folded Guante limestone crop out, separated

Photograph 1. Northward view along axis of breached Borrachera anticline from Lat. 30°22'20" N.; Long. 104°56'15" W. Left middle background is Bosque Bonito syncline. Right middle background is Sierra del Porvenir. Left far horizon is Eagle Mountains. Right far horizon is Tierra Vieja.

Photograph 2. Westward view from west flank of Borrachera anticline at Lat. 30°23'45" N.; Long. 104° 57'30" W. Anticlinal fold in Lujan limestone is overturned eastward.

by valleys of bolson fill. They probably represent a southern extension of the Sierra de la Cieneguilla, the next range westward. Between these folded ridges of Guante limestone and the Sierra Pilares to the east, three hills of Guante crop out amid the bolson fill. Average dip of strata in these hills is about 20° westward.

Along the southern part of the map area is the outcrop of a large thrust sheet. It rests in different places on the Guante, Lujan, Bosque Bonito, and Buda limestones (structure section B-b', fig. 3). The dip of the fault is not known. The overthrusting of this sheet northeastward towards the Diablo Platform agrees with the regional pattern of thrusting. The theory of de Sitter (1956, p. 239) suggests that the asymmetry of the Borrachera anticline and the thrusting northeastward is a result of lateral compression acting upon a sedimentary series that wedges towards the eastern margin of the basin.

NORMAL FAULTS

The Sierra Pilares is a deformation feature of Laramide folding that owes much of its relief to middle or late Tertiary block-faulting. The eastern limb of the Borrachera anticline is cut by a large north-trending normal fault that runs the length of the map area. The eastern block has been downthrown an unknown amount, but probably more than 1,000 feet. To the east of this fault and subparallel with it is the Benigno fault described by Allen (1957, p. 34), who estimated its displacement as 1,500 feet. This fault is downthrown to the west and the graben thus created and subsequently partly filled with debris is the

Benigno bolson.

Many smaller normal faults are mapped in the Sierra Pilares. Most of these faults are longitudinal to the fold axis and strike north to northwestward. Downthrow on most of them is to the west. One may be classified as a longitudinal crestal fault, since its position closely corresponds to the axis of the Borrachera anticline. Its vertical displacement is estimated to be 500 feet; it brings the Pilares sandstone on the eastern upthrown side against the Provenir sandstone on the western side.

Several subparallel longitudinal faults are exposed near the plunging nose of the fold. Essentially they form an alternating series of horsts and grabens with displacements of 50 to 200 feet. One of these faults is clearly younger than some of the Laramide thrusting, for it cuts the upper plate of the thrust sheet.

The faults that have trends ranging from north to northwest represent the final features produced by an ever-changing Cretaceous and Tertiary stress field. The magnitude and direction of the stress difference was variable in both space and time. The normal faults adjusted the terrain on account of the release of compressional stress by folding and thrust faulting or other causes. In terms of the Anderson (1951) theory, the normal faults represent shear planes parallel to the direction of the horizontal median stress, and bisected by the direction of principal stress, that of gravity.

On the east side of the Sierra Pilares in the Tarantula gravel there are two small piedmont scarps. They probably represent renewed

Photograph 3. Eastward view from west bank of Arroyo Benigno at Lat. 30°21'10" N.; Long. 104°52'10" W. Background is Sierra de los Fresnos. Plane surface is top of Q70 gravel capping bolson fill.

movement during the Quaternary Epoch along deeply buried faults. On the west side of the Sierra Pilares in the bolson fill is a small piedmont scarp that appears to be the continuation of a fault cutting the Cox Sandstone.

The western limb of the Borrachera anticline in the map area does not seem to be cut by faulting of any consequence, but the strata appear to dip westward under the bolson fill. Clutterbuck (1958, p. 14) reported a normal fault downthrown to the west bounding the west side of the Bosque Bonito syncline; his estimate of the displacement was 1,000-1,500 feet. Vest (1959) also mapped this same fault as forming the westward boundary of the southern continuation of the Bosque Bonito syncline into the Sierra Porvenir area. The displacement of this fault lessens southward, and the fault appears to die out near the northern edge of the Sierra Pilares.

The absence of a normal fault, downthrown to the west, forming the western boundary of the Sierra Pilares conveniently resolves the question of why the thick Tarantula gravel is present on the east side of Sierra Pilares but not on the west side. This thick bajada gravel is a consequence of the first normal faulting of large extent and thus would never have formed on the west side of this part of the range. In short, that portion of the range north of Sierra Pilares is a horst, while the Sierra Pilares is not. Unfortunately, this explanation for the absence of the Tarantula gravel cannot be extended northward to the Sierras Porvenir and Bosque Bonito.

In the northwestern part of the map area, near Rancho Puerto Alto,

Photograph 4. Westward view from west flank of Borrachera anticline at Lat. 30°23'45" N.; Long. 104° 57'30" W. Slopes are Lujan limestone. Ledge-forming Guante limestone in left middleground is on upthrown side of northwest-trending fault. Middle background is Cuervo bolson. Elongate mountain in right background marked by top of lechuguilla stalk is possible southern part of Sierra de la Cieneguilla.

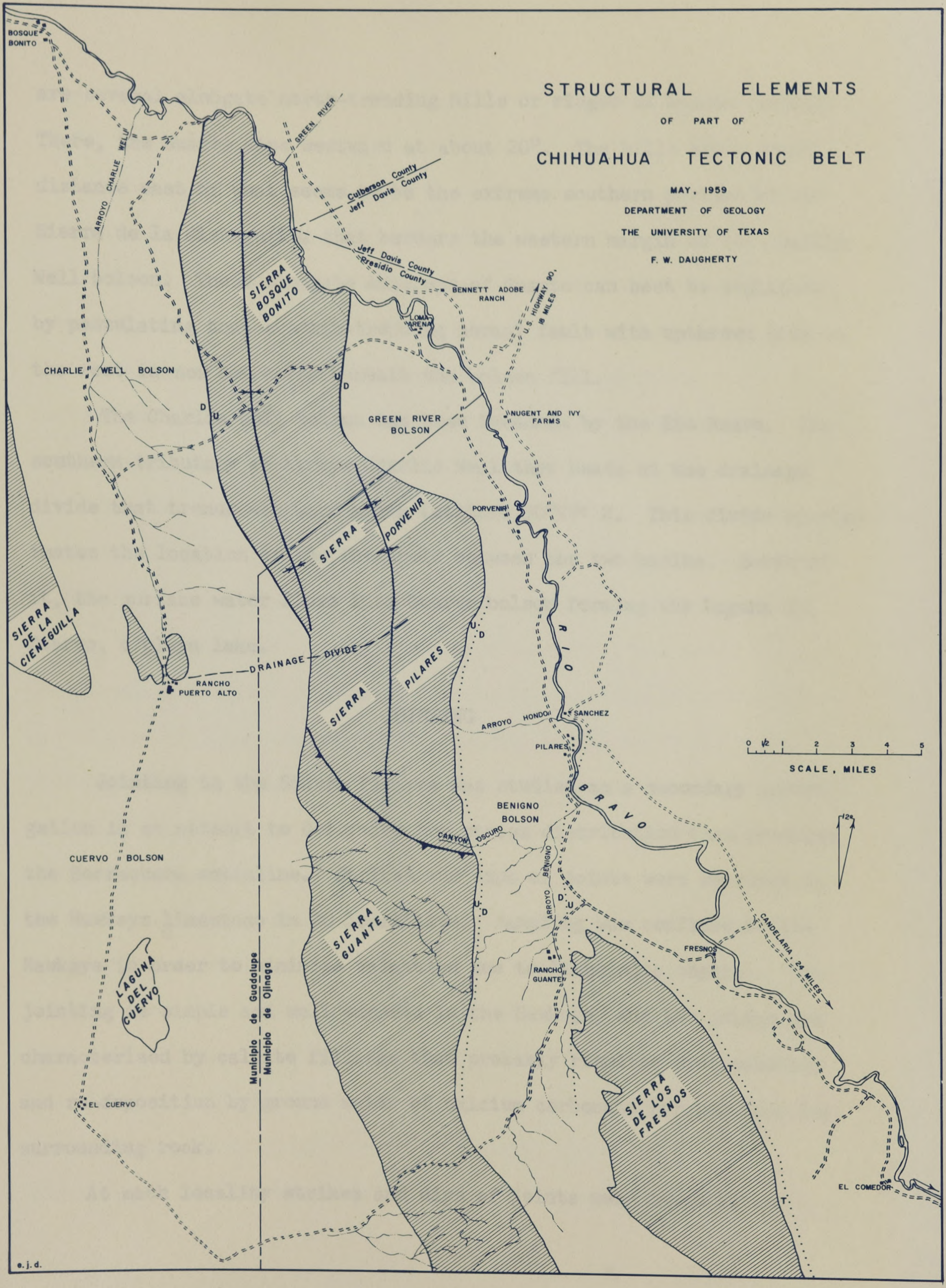

STRUCTURAL ELEMENTS
OF PART OF
CHIHUAHUA TECTONIC BELT
MAY, 1959
DEPARTMENT OF GEOLOGY
THE UNIVERSITY OF TEXAS
F. W. DAUGHERTY
BOSQUE BONITO
ARROYO CHARLIE WELL
GREEN RIVER
Culberson County
Jeff Davis County
Jeff Davis County
Presidio County
BENNETT ADOBE RANCH
U.S. HIGHWAY 90, 18 MILES
LOMA ARENA
SIERRA BOSQUE BONITO
CHARLIE WELL BOLSON
GREEN RIVER BOLSON
NUGENT AND IVY FARMS
PORVENIR
SIERRA PORVENIR
SIERRA DE LA CIENEGUILLA
DRAINAGE DIVIDE
RANCHO PUERTO ALTO
RIO BRAVO
SIERRA PILARES
ARROYO HONDO
SANCHEZ
PILARES
0 1/2 1 2 3 4 5
SCALE, MILES
BENIGNO BOLSON
CANYON OSCURO
ARROYO BENIGNO
CUERVO BOLSON
SIERRA GUANTE
LAGUNA DEL CUERVO
Municipio de Guadalupe
Municipio de Ojinaga
RANCHO GUANTE
FRESNOS
CANDELARIA, 24 MILES
SIERRA DE LOS FRESNOS
EL CUERVO
EL COMEDOR
e. j. d.

Figure 2

are several elongate north-trending hills or ridges of Guante limestone. There, the Guante dips westward at about 20°. The hills are a short distance east of what seems to be the extreme southern portion of the Sierra de la Cieneguilla that borders the western margin of the Charlie Well bolson. These elongate outcrops of Guante can best be explained by postulating that a north-trending normal fault with upthrown side to the west is now concealed beneath the bolson fill.

The Charlie Well bolson has been breached by the Rio Bravo. Its southern tributary is Arroyo Charlie Well that heads at the drainage divide that trends westward along Latitude 30°27' N. This divide approximates the location of the threshold between the two basins. South of it, the surface water flows into Cuervo bolson forming the Laguna del Cuervo, a playa lake.

JOINTING

Jointing in the Sierra Pilares was studied as a secondary investigation in an attempt to determine the stress distribution that produced the Borrachera anticline. Strikes and dips of joints were measured in the Hawkeye limestone in 20 localities. Sampling was confined to the Hawkeye in order to minimize variation due to lithologic changes. The jointing is simple and well exposed in the Hawkeye, and the joints are characterized by calcite fillings that probably resulted from solution and re-deposition by ground water of calcium carbonate derived from the surrounding rock.

At each locality strikes and dips of joints were measured and a record made as to which set was the more continuous against which lesser sets were seen to terminate. The multiplicity of joints in places dictated selective data taking. The irregular or obscure joints without consistent orientation were discounted. Kurie (1956, p. 7-10) has outlined a weighting method for sampling joint populations that appears to be practical. The joint diagram (diagram 1) presented cannot be considered as a complete indication of the jointing in the Borrachera anticline but merely a summary of what the writer believes to be the major joint pattern in 20 localities.

Many structural geologists assume that jointing in layered rocks has its origin in deformative stress that acted during a folding episode. Since the Borrachera anticline is a north-trending asymmetric feature it appears that the maximum compressional stress acted in a horizontal east-west direction if the fracture pattern is explainable by the present shape of the uplift. Hubbert (1928, p. 83-84) demonstrated that when axes of individual folds are parallel to the trend of the fold belt, the greatest compressional stress must have been applied at right angles to that part of the range.

It is possible, however, that some joints are the result of later faulting and thus may have little or no relationship to the local configuration of the bedding surfaces. Another possibility is that some joints may be the result of a deformation distinct from that which produced the fold. Nevin (1949, p. 152) doubted that a later deformation could produce another joint system in a region once broken by systematic jointing. He failed, however, to remark that joints in limestone readily heal with calcite, thus rendering them as rigid and therefore as susceptible to jointing as in any previous state.

According to the theory of Anderson (1951), shearing planes, either faults or joints, may develop in planes that are parallel to the median stress direction and make an acute angle bisected by the direction of the largest stress, whereas tension joints will be oriented parallel to this largest stress and perpendicular to the smallest stress.

It is unlikely that the regional minimum stress orientation was other than vertical during the folding and jointing episode. The resultant of regional compression with the maximum and minimum stress orientations in a horizontal plane would be strike-slip faults. Shear joints, if present, should make an acute angle bisected by the maximum stress direction, and should therefore trend approximately N. 60° E. and N. 60° W. The joint diagram shows that nearly all joints represented are essentially either longitudinal joints paralleling the fold axis or dip joints striking at right angles to the fold axis. Inspection of the diagram indicates that the few joints that strike N. 60°-70° W. and N. 60°-70° E. are merely representatives of the prominent set of dip joints that has a considerable variation in strike. None of the joints shown can reasonably be said to be shear joints according to the definition of the Anderson theory.

Observed overthrusting and asymmetry of folds in the Sierra Pilares establishes the fact that vertical relief of stress at the time of folding must have been comparatively easy. Overthrusting, to accord with the Anderson theory, can only occur when the maximum and median

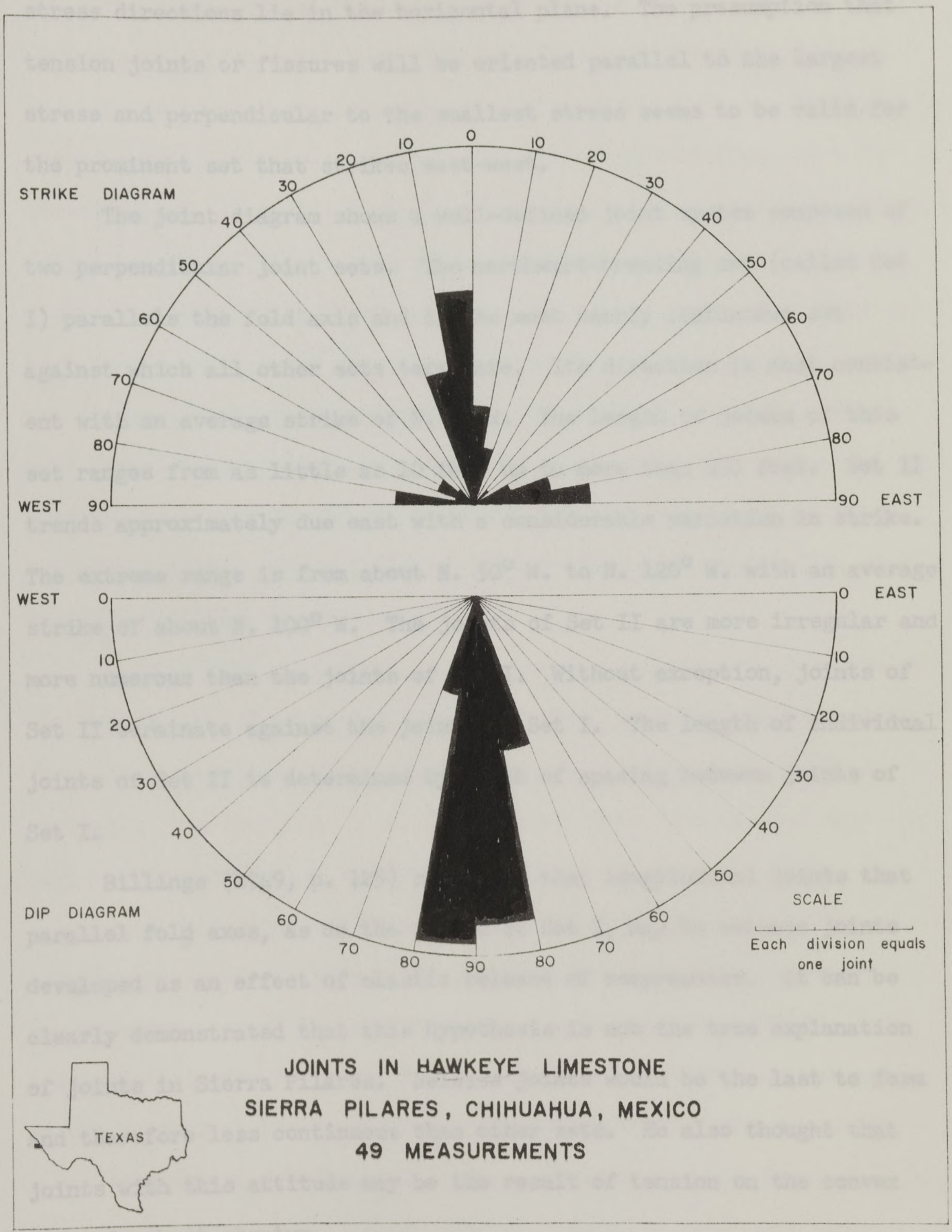

STRIKE DIAGRAM
0 10 20 30 40 50 60 70 80 90
WEST
EAST
DIP DIAGRAM
SCALE
Each division equals one joint
TEXAS
JOINTS IN HAWKEYE LIMESTONE
SIERRA PILARES, CHIHUAHUA, MEXICO
49 MEASUREMENTS

Diagram 1

stress directions lie in the horizontal plane. The presumption that tension joints or fissures will be oriented parallel to the largest stress and perpendicular to the smallest stress seems to be valid for the prominent set that strikes east-west.

The joint diagram shows a well-defined joint system composed of two perpendicular joint sets. The northward-trending set (called Set I) parallels the fold axis and is the most nearly continuous set against which all other sets terminate. Its direction is most consistent with an average strike of N. 7° W. The length of joints of this set ranges from as little as 10 feet up to more than 100 feet. Set II trends approximately due east with a considerable variation in strike. The extreme range is from about N. 50° W. to N. 120° W. with an average strike of about N. 100° W. The joints of Set II are more irregular and more numerous than the joints of Set I. Without exception, joints of Set II terminate against the joints of Set I. The length of individual joints of Set II is determined by width of spacing between joints of Set I.

Billings (1949, p. 125) suggested that longitudinal joints that parallel fold axes, as do the joints of Set I, may be release joints developed as an effect of elastic release of compression. It can be clearly demonstrated that this hypothesis is not the true explanation of joints in Sierra Pilares. Release joints would be the last to form and therefore less continuous than other sets. He also thought that joints with this attitude may be the result of tension on the convex side of a bent stratum.

The joints of Set I do not seem to belong to one set only but to two subsets. The strikes are identical, but each subset dips so as to converge under the anticline. Moreover, the joints dip at approximately right angles to the plane of stratification rather than to the horizontal plane. It would thus appear that the joints of Set I were formed either before or early in the folding episode because the folding has disturbed their typical vertical position. In this case the joint pattern becomes clear only when the plane of stratification is rotated to its original horizontal position. De Sitter (1956, p. 133) reported that Deenan, who studied many joints in a coal mine, found that all were oriented perpendicular to the plane of stratification instead of the horizontal plane. Nevin (1949, p. 154) related such jointing to what he terms "initial compressive shock."

All the 26 longitudinal joints measured have dips that depart from the vertical by 5° or more. Following rotation of the plane of stratification to the horizontal, 21 joints assumed dips within 5° of the vertical. The remaining 5 joints, however, were thus rotated past the vertical with resultant dips averaging 77°.

This ostensible conflict with the findings of Deenan can be resolved quite easily. Deenan assumed that the deformative stress had a constant orientation to the horizontal plane. All the joints he measured were oriented perpendicular to the plane of stratification instead of the horizontal plane. He logically concluded that the joints he measured originated before the folding. Most of the longitudinal joints in the Borrachera anticline were formed before and some were formed continuously during the folding. In the anticlinal folding of a competent rock mass, a local tensional stress can be expected in the outer arc of the fold perpendicular to its axis. This direction would be the local minimum stress orientation with the overburden constituting the median stress. The joints that were not vertical at the time they were formed may be the result of stresses oriented to the bedding surfaces rather than to an invariable horizontal plane.

E C O N O M I C   G E O L O G Y

PETROLEUM

At the present time the nearest petroleum production is from rocks of Permian age in the western part of the Delaware Basin in Culberson, Reeves, and Pecos Counties, Texas, about 90 miles northeast of the Sierra Pilares. Although little is known about the subsurface geology of the Chihuahua tectonic belt, this extensively folded and faulted geosynclinal sequence offers considerable promise for the eventual production of petroleum.

Three important factors lead the writer to believe that the Sierra Pilares is the most promising locality for petroleum production in that part of the Chihuahua tectonic belt studied to date. First: Thick deposits of potential reservoir rock are present. Cretaceous, Jurassic, Permian, and pre-Permian Paleozoic deposits, if present, are possible reservoir rocks. The major unconformity between the truncated pre-Permian rocks and the overlying Permian rocks offers a possibility for a petroleum trap in the pre-Permian strata. The unconformity between the Permian and the Cretaceous also offers the possibility of a trap in the Permian strata. Wedge-outs in the eastward-thinning Jurassic and Cretaceous rocks may furnish possible petroleum reservoirs. Second: The Borrachera anticline is a favorable structural feature of large areal extent. Moreover, this anticline is not so complexly folded and faulted as is much of the adjoining region. An additional favorable factor is the absence of local vulcanism. Third: The oil prospector,

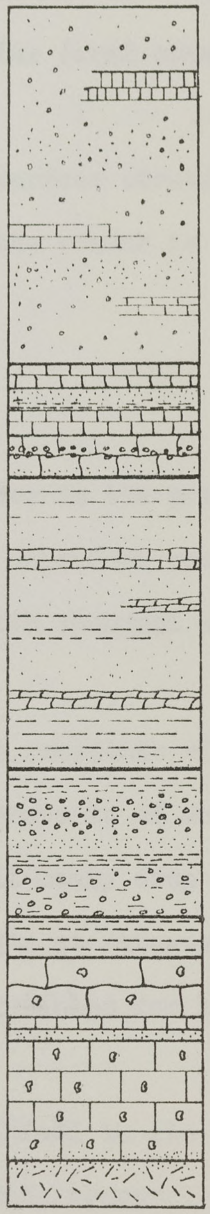
CONJECTURED SUBSURFACE SECTION

BORRACHERA ANTICLINE

MUNICIPIO DE OJINAGA, CHIHUAHUA, MEXICO

AGE	ROCK UNIT	GUESSED THICKNESS IN FEET	DESCRIPTION
Cretaceous	Las Vigas	3,000	cgl, ss, ls
	Torcer	300	ls, ss, sh
Late Jurassic	Malone	200	ls, cgl, ss
Permian	Pinto Canyon, Alta	2,500	ls, ss, sh
Pennsylvanian	Cieneguita	1,200	sh, cgl
Mississippian—Devonian	Helms Canutillo	200	sh
Devonian—Silurian	Fusselman	500	cherty ls
	Simpson Montoya	100	ls, ss
Ordovician—Cambrian	El Paso Bliss	1,000	cherty dol
			ss, arkose
Precambrian			

ROCK SYMBOL



TOTAL DEPTH 9,000 feet

Section 2

COMPILED BY RICHARD A. CAMPBELL
DEPARTMENT OF GEOLOGY
THE UNIVERSITY OF TEXAS
MAY 1959

commencing a well in the Borrachera anticline, is approximately 10,000 feet closer, stratigraphically, to possible Coahuilan, Jurassic, or Paleozoic production. The Pemex No. 1 Chapo well located approximately 15 miles southwest of Ojinaga, Chihuahua, began in the Gulfian "Eagle Ford" (that is, Chispa Summit or Ojinaga) and drilled to a depth of 10,500 feet in Comanchean strata according to Diaz (oral communication, July 1958).

Section 2 is an interpretation of the subsurface stratigraphy of the Sierra Pilares. For a fuller description, the reader is referred to Campbell (1959).

WATER

From the viewpoint of human resources, water is the prime essential. The development of civilization has been dependent upon the supply available. Those who live in regions favored with abundant water seldom appreciate its importance.

Agriculture is the only livelihood for the residents of the map area. Farming along the floodplain of the Rio Bravo is of much greater importance than livestock raising. The principal money crop is cotton which is hauled by truck to the nearest cotton gin at Zaragoza near Juarez, Chihuahua. Wheat, corn, fodder, and vegetables for local consumption comprise the balance of farm produce.

The flow of the Rio Bravo depends upon rainfall in its drainage basin between the Sierra Pilares and Elephant Butte reservoir on the Rio Grande north of El Paso, Texas. Allen (1957, p. 13) gives the average annual rainfall at Candelaria, Texas, for the period 1948-1956 inclusive as 7.43 inches.

All tributaries of the Rio Bravo in the map area are ephemeral streams that flow only for short periods following rain on their drainage basins. The only large tributary of the Rio Bravo on the Mexican side in the map area is the northward draining Arroyo Benigno. Arroyo Dieciocho or Van Horn Creek drains a large area on the Texas side and enters the Rio Bravo about one mile north of Pilares.

At Pilares an acequia (irrigation canal) more than a mile long diverts water from the Rio Bravo. This acequia is so well constructed that a flow, however slight, delivers water to this communal canal. The supply of water for irrigation is dependent solely on rain which falls mostly in the months of June, July, August, and September.

The inhabitants of Pilares derive water for human consumption from shallow dug wells in the Quaternary alluvium. Howard Gibson (oral communication, June 1958) stated that a dug well on his farm at Pilares, Texas had been pumped at 200 gallons per minute, the pump capacity, without lowering the water level. The water from this well is not potable, largely because it has taken into solution large quantities of various solids during its travel in the alluvium beneath the Rio Bravo.

Clutterbuck (1958, p. 40) reported that Moody L. Bennett on his Adobe ranch in Texas 15 miles to the north has water wells capable of producing 1,400 gallons per minute from a depth of 87 feet in the Quaternary alluvial fill. This water is suitable for domestic consumption largely because the aquifer is recharged locally from stream flow down

Green River, Sand Creek, and other tributaries to the Rio Bravo.

It would seem that the supply of underground water in the alluvium or bolson is adequate to supply the irrigation needs of the Pilares community. Because of the extensive dissected terraces the land available for farming purposes is limited to the floodplain of the Rio Bravo. Most of this floodplain is under cultivation at the present time.

Despite the availability of irrigation water at shallow depths in the alluvium or bolson fill, Pilares does not have an irrigation well at this time. The principal deterrent to utilization of underground water is lack of capital. The individual tracts of land are generally too small to afford an irrigation well and pump but a joint enterprise utilizing the communally owned acequia for distribution is quite feasible. A combined use of the almost cost-free river water when available and pumped water as needed would be to the best interests of the residents.

The only drilled well in the map area is located at Rancho Puerto Alto in the northern edge of Cuervo bolson on the west side of Sierra Pilares. This well is 450 feet deep and probably produces from bolson fill. This water is suitable for domestic consumption. The quantity of water available from this well is unknown but is adequate for the livestock requirements of the ranch. A possibility exists that a large supply of underground water is available in the Cuervo bolson region. If so, this is the only large area of arable land.

METALS

The Sierra Pilares is non-mineralized even though local residents have a vast stock of stories about abandoned mines. There is no doubt that northern Chihuahua as a whole is mineralized to some degree. Although the presence of igneous intrusions is not everywhere requisite for mineral deposits, their absence serves to heighten the belief that no deposits of consequence occur in the map area.

Allen (1957, p. 54-55) reported finding two abandoned silver mines in the Sierra de los Fresnos. Both mines are in mineralized fissures, one in the Guante limestone and the other in the Benigno Formation. Allen stated that low-grade ore was present in both mines. Unfortunately, he failed to report the mineral found or its assay value.

Evidence that silver had been smelted near Pilares is first reported in Emory (1857, p. 90). The writer was able to locate the smelter slag; it is 100 yards east of the Pilares cemetery and is indicated on the geologic map by the symbol S.

The slag is highly siliceous, suggesting that it might have come from the Cox Sandstone. The small amount of slag still intact at this site probably indicates that the mining venture was unprofitable. Pilares was the logical spot for a smelter operation because it afforded protection from the Apache Indians. The mining activity probably took place during the time that Pilares was a presidio or military colony which was from about 1783 to 1810 according to Raht (1919, p. 45).

\- The End -

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GEOLOGIC MAP
OF
SIERRA PILARES
CHIHUAHUA, MEXICO
MAPPED BY
R.A. CAMPBELL F.W. DAUGHERTY
SUPERVISED BY R.K. DEFORD
DEPARTMENT OF GEOLOGY
THE UNIVERSITY OF TEXAS
MAP PRINTED FEBRUARY, 1959
EXPLANATION
QUATERNARY
TERTIARY
CRETACEOUS
QTb - bolson fill on west
Q90 alluvium
Q80 gravel
Q70 gravel
Q60 gravel
QTb bolson fill on east
Tt *Tarantula (?) gravel
Tv Vieja Group (undifferentiated)
Kbu Buda Ls.
Kd Del Rio Fm.
Kbb *Bosque Bonito ls.
Kl *Lujan ls.
Kg *Guante ls.
Kc Cox Ss.
Kh *Hawkeye ls.
Kpo *Porvenir ss.
Kpi *Pilares ss.
Kpu puddingstone
* Field name not formally proposed
Strike and dip of beds
Strike and dip of overturned beds
Normal fault
Concealed fault
Thrust fault (teeth on upper plate)
Measured section I
Fossil collection locality
Anticline
Overturned anticline
Syncline
Altimeter elevation (feet)
Smelter slag
Windmill
SCALE IN FEET
STRUCTURE SECTIONS
BORRACHERA ANTICLINE
RIO BRAVO
ARROYO BENIGNO
Bolson de Cuervo
DRAINAGE DIVIDE
RANCHO PUERTO ALTO
UNMAPPED AREA
TEXAS
MEXICO
HUDSPETH CO.
JEFF DAVIS CO.
COYAME
RIO GRANDE
ARROYO HONDO
ARROYO QUINTANA
PILARES
D SANCHEZ
TO EL CUERVO 15 MILES
TO BOSQUE BONITO 18 MILES
TO FRESNOS, 7 MILES
TO CANDELARIA 23 MILES